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Engineering Education in Germany: An Industry Perspective

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In general, the tasks of 'Ingenieurs' (= engineers in German) in the economy, and in industry in particular, are the conception, design, realization, diffusion and operation of complex equipment, plants and systems in various areas of technology. Corresponding to the development of a new product, individual fields of activity have arisen for Ingenieurs with specific professional profiles in research and development, product development, planning, sales, manufacturing, construction, installation and service. From an industry perspective, the goal of education and training for Ingenieurs must lie in achieving high professional standards that will allow Ingenieurs independently to assume responsibility for tasks in the above-mentioned fields. The system of initial and continuing education and training for Ingenieurs in Germany is designed in such a way that the demands of the economy are met. This article focuses on these demands and uses suitable models to show ways that they can be satisfied.

INTRODUCTION

THE KNOWLEDGE and ability of personnel are the primary requirements of effective performance and competitiveness and thus for the sustained success of a company. Above all else is the professional success of the staff members themselves. This especially applies to Ingenieurs working in industry who face the task of converting new technical possibilities into innovative products in ever shorter periods of time.

For a successful engineering career, both a solid initial education as well as continuing education and training throughout one's professional life are indispensable. An engineering education can and should convey the fundamentals of a discipline, as well as the knowledge necessary for applications in the initial years of professional practice. Since new demands constantly arise on the job, specialized and general continuing education are needed to maintain the professional skills of Ingenieurs throughout their careers.

Initial engineering education, as well as specialized and general continuing education, are thus two aspects that closely interrelate with the overall initial and continuing education and training system. Individual goals, from the viewpoint of industrial practice, should be oriented around engineering tasks in industry and on the qualifications that these tasks require.

ENGINEERING TASKS IN INDUSTRY

The tasks of Ingenieurs in industry are conception, design, realization, diffusion and operation of complex devices, equipment and systems in various areas of technology. Such applications arise in all areas of life.

The development of a new product follows the various cycles of technical innovation. At the beginning there may be a discovery of a natural phenomenon and the idea for its technical utilization. The explanation of newly discovered phenomena is the task of basic research, which is phenomenon oriented. Until a marketable product emerges, a long path follows in which many people of various backgrounds collaborate purposefully. These collaborations take place in various engineering tasks each with specific professional activities such as research and development, product development, planning, distribution, manufacturing, construction, installation and service. From an industry perspective, the goal of education and training for Ingenieurs must lie in achieving high professional standards that will allow Ingenieurs independently to assume responsibility for tasks in such fields.

The individual engineering tasks, however, place differing demands on methodological approaches. In research and development, the theoretical–abstract treatment of the problem is of primary importance; the emphasis in manufacturing, construction, installation and service is more in the practical–concrete realm. Every engineering task requires a combination of theoretical and practical approaches, though in differing combinations. In a similar way, students' aptitudes, inclinations, abilities and skills are variously pronounced. The initial education and continuing education and training system for Ingenieurs must take into consideration these demands from professional practice as well as the personal characteristics of students and personnel.

DIFFERENTIATED SYSTEM OF INITIAL ENGINEERING EDUCATION

The necessary emphasis on theory and practice in the differing groups of a company's technical staff is illustrated in Fig. 1. The required education profile for semi-skilled workers, skilled workers ('Facharbeiter'), technicians ('Techniker'), engineering assistants, engineers ('Ingenieurs') and natural scientists are placed on the chart in accordance with the competency demanded. The qualifications for an Ingenieur requires a high minimum level of theoretical comprehension of the necessary specialized knowledge as well as a corresponding minimum level of practice and application orientation (broken line).

Engineering education at universities ('Hochschulen') is expected to impart a high level of qualification (Fig. 2). This is represented in the diagram by an arc, which indicates the separate areas of engineering qualifications. Differing education and qualification profiles at the university level are depicted by vectors. Placing the necessary qualification profiles for individual engineering tasks along the arc, the total required competency is revealed, together with the corresponding different emphases on theory and practice. The necessary vector length (total competency) is the same, regardless of direction (competency profile).

Since differing qualification profiles cannot easily be imparted in a uniform university system, industry has understandably demanded a structured system of initial engineering education with independent university types and differentiated educational profiles. The demands on educational profiles stem from the demands of the required qualification profiles. Correspondingly, the education at different types of universities should be of the same standard but of a different nature, as expressed in the diagram by the vectors of identical lengths but different directions.

A differentiated system of engineering education has been developed in the Federal Republic of Germany with differing university profiles, e.g. 'Universitäten' and 'Fachhochschulen', in accordance with industrial requirements. Graduates from both types of institutions find tasks in industry that correspond to the qualifications they gained during their academic courses.

For example, in 1990 Siemens employed in Germany about 40,000 technical and scientific graduates from 'Universitäten' and 'Fachhochschulen'—about 34,000 were Ingenieurs and 6000 scientists. In the case of the Ingenieurs, the ratio between 'Fachhochschule' and 'Universität' was about 2.5:1. Looking at the individual functional areas, the same ratio was 1:4 in research and exactly the reverse, 4:1, in production and service (Fig. 3).

The independent profiles of the two types of universities have proved successful and, from an industry perspective, should be maintained and further developed. They should be rapidly introduced in the new federal states in eastern Germany.

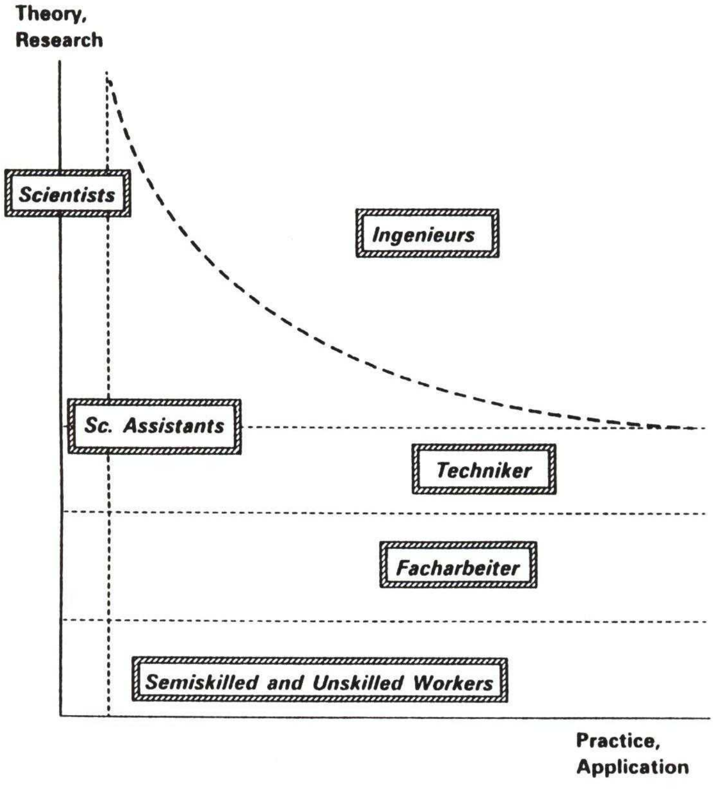

Fig. 1. Emphasis on theory and practice in engineering and scientific professions.

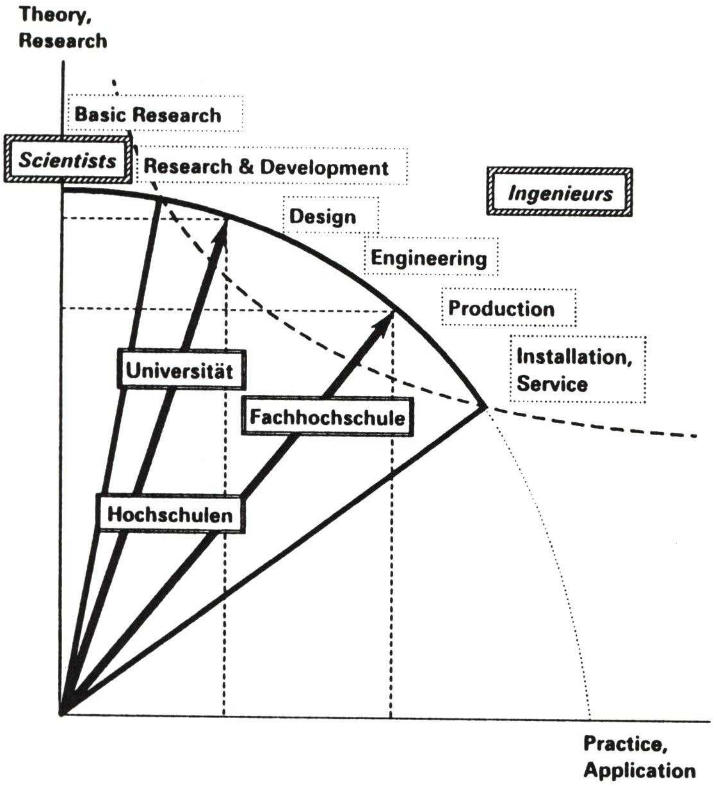

Fig. 2. Different education profiles of Ingenieurs at German 'Hochschulen'.

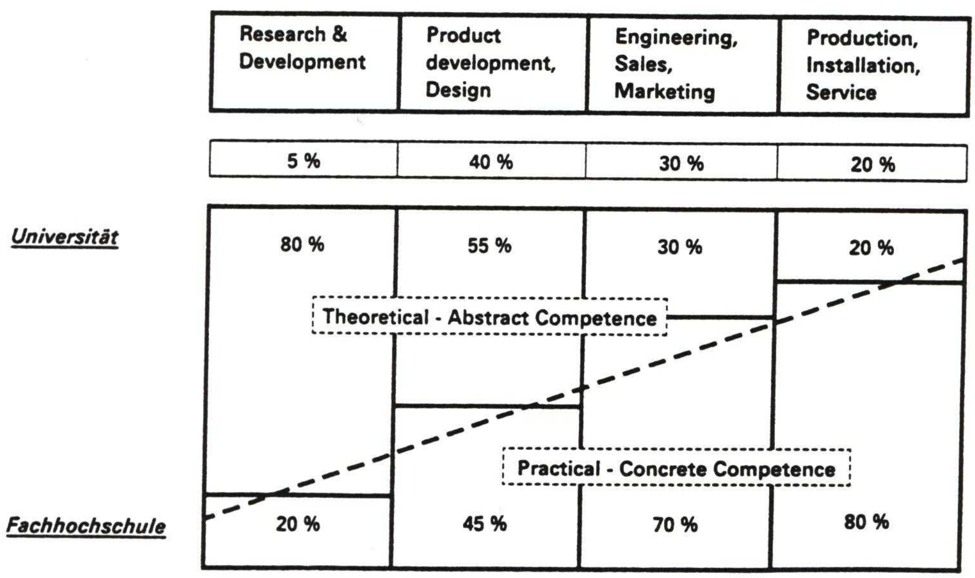

Fig. 3. Theoretical and practical shares of required competence in professional fields for 'Ingenieurs' and graduates of 'Universitäten' and 'Fachhochschulen' at Siemens.

PROFESSIONAL DEMANDS ON INGENIEURS IN INDUSTRY

An analysis of an Ingenieur's work in industry shows that it consists of different tasks characteristic of a particular job. The activities depend on various factors such as special area, functional area, plant size, etc., each placing specific demands on the staff member's knowledge and ability. Although these tasks differ greatly, the basic structure of the knowledge required is the same.

The professional competence of Ingenieurs can also be illustrated with the two axes 'depth of knowledge' and 'breadth of knowledge' shown in

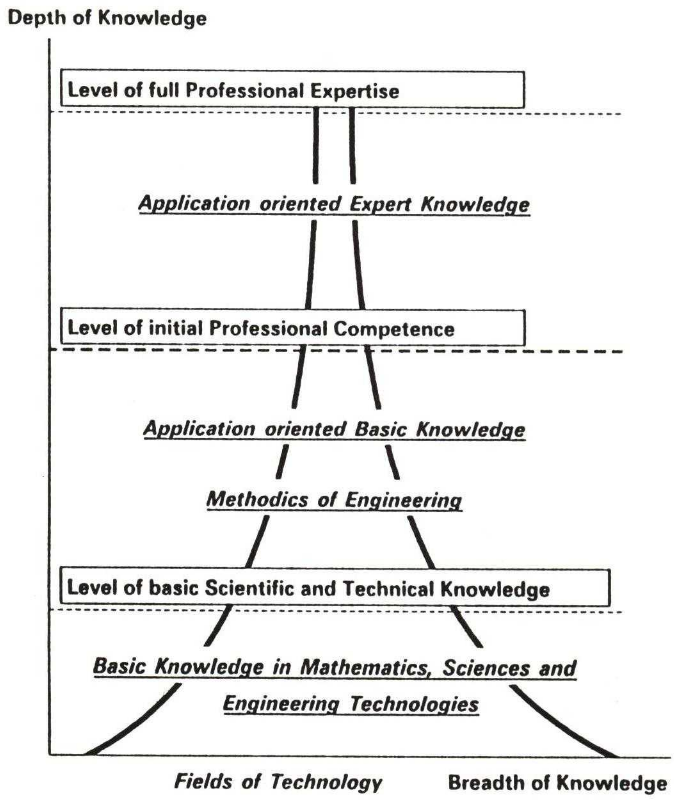

Fig. 4. Required knowledge profile for 'Ingenieurs' in industry.

Fig. 4. The specialized areas are located along the 'breadth of knowledge' axis. 'Depth of knowledge' shows the levels of knowledge in these areas up to the level of full professional expertise.

No one is in a position to become an expert in all areas. Broad knowledge is, in general, only feasible at the foundation level. Specialization is normally only possible in one, more or less, limited area. Job requirements in industry are thus adjusted to the mental abilities of the personnel (Fig. 4).

The basis of the necessary engineering qualifications is a wide spectrum of knowledge in mathematics, natural science and technology. This basic knowledge is essential for a broad understanding of natural phenomena and their utilization in technical applications, but also serves as a foundation for attaining a breadth of knowledge in one field of application. A broad foundation is also an important prerequisite to enable Ingenieurs to communicate with scientists from other areas.

However, a command of the basics is not, in itself, sufficient for ensuring professional competence in industry. In order to meet the demands of the job, Ingenieurs need additional in-depth fundamental knowledge of their specialized fields, general knowledge of problem-solving methods in engineering and special application knowledge in accordance with workplace demands.

In-depth general knowledge of a field of application gives the Ingenieurs an overview of the entire scope of the task, the ability to see how his/her special problem solution fits into the overall solution, and the competence to master interface problems. Knowledge of system functions in the field in question and an appreciation of technological possibilities (hardware and software) is needed. The procedural methods of engineering science are of help. In light of the growing complexity of modern devices, equipment and systems, the ability to see things as a whole, to think in terms of systems and to communicate at a systems level with all Ingenieurs working on the project gains in importance.

Finally, for the attainment of full professional competency, a further intensification of knowledge in the areas of specialization is necessary with reference to the demands of the workplace. Depending on the task at hand, this can take place either in the direction of more depth of knowledge in a limited field or in the opposite direction, towards more breadth of knowledge. Whereas a 'specialist' moves to the very limits of knowledge in a narrow, specialized field, a 'generalist' strives for increasing competency in a broad area with an achievable depth.

A MODEL FOR AN EDUCATION AND TRAINING SYSTEM FOR INGENIEURS

If Ingenieurs are to satisfy fully the varied job demands in industry, they must acquire the necessary knowledge and ability; they are, consequently, dependent on the adequacy and efficiency of the education and training systems.

Education alone is unable to teach Ingenieurs all they need to know during their professional careers. Only the combination of initial and continuing education yields the full qualifications needed for a position in industry. For economic reasons, engineering education must limit itself to imparting a broad foundation; continuing education has the task of offering a broad range of subjects that will enable Ingenieurs to attain full professional expertise, and to maintain this expertise throughout their professional careers.

Engineering education provides graduates with their initial professional qualifications and enables them to begin their professional careers. What demands does industry place on these initial qualifications?

Engineering Education

Professional practice expects two partially contradictory qualifications from young Ingenieurs. On the one hand, they must have high professional mobility and flexibility, i.e. the ability to adjust quickly to new problems, for their own interests or because of job demands. This presupposes a breadth of basic knowledge. On the other hand, initial professional requirements demand that young graduates are able to master efficiently the transition to workplace demands. This presupposes, however, that graduates have already been exposed to practice-oriented problems during their studies. The goal of engineering education from industry's point of view must, therefore, be the attainment of high professional mobility with sufficient initial professional competence. In light of the limited time for engineering education, curriculum design must reach a compromise between these two requirements. Both goals can be reached with a model patterned after engineering education as practised in Germany (Fig. 5).

The core of qualifications to be attained during engineering education should comprise a broad spectrum of mathematical, scientific and technical knowledge. This should extend to all subjects under consideration, thus laying the foundation for subsequent professional mobility. In this respect, teaching should not go into too much depth but rather should give the students a balanced overview and teach them how they can independently acquire the additional knowledge they need both during their studies or on the job. The sound teaching of a broad foundation during engineering studies is also important because experience shows that it is difficult to bridge gaps in knowledge once a professional career has begun.

Building on the fundamentals, the teaching of application-oriented technical knowledge should take place in the form of a selective deepening in a few technical spheres of activity. Teaching here should go into somewhat more detail; the depth of

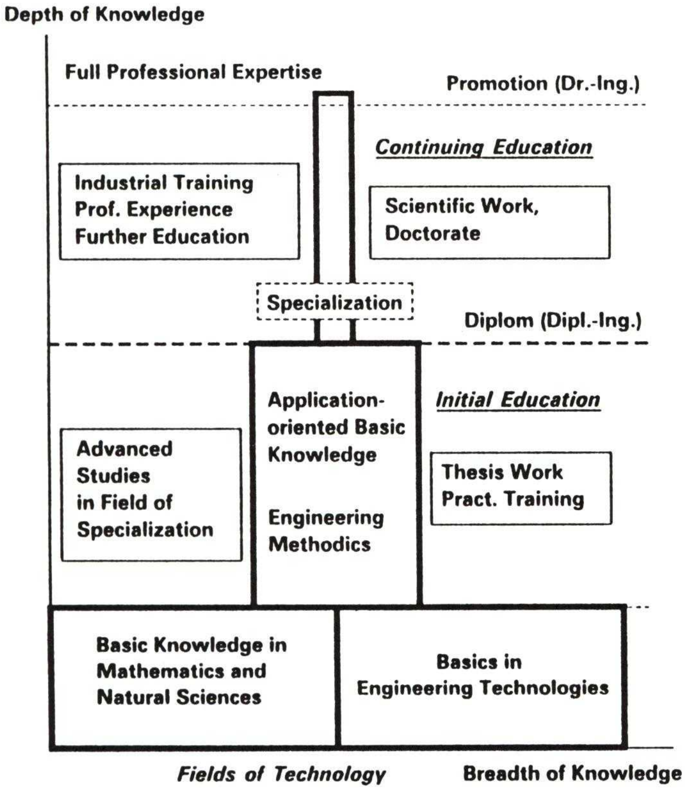

Fig. 5. Model for a system of education and training for 'Ingenieurs'.

knowledge is limited by the level that is rationally attainable within the time allotted during engineering studies.

A rough assessment of the individual fields of knowledge shows that an optimum compromise in engineering education can be attained when approximately one-third of the entire duration of education is devoted to each of the three educational segments: mathematics–natural science, technical foundations and intensification in a freely-chosen field of application.

In addition to the teaching done in lectures, seminars and laboratory experiments, German engineering education is especially marked by its high degree of practical orientation. Practical orientation, however, can only be fully implemented when it is actively pursued by both professors and students and when it is taken into full account in curriculum planning.

Professors achieve and maintain a practical orientation if they, for example:

- have industry experience (at least 5 years) before their university appointment;
- actively work together with industry (R&D, continuing education);
- spend their sabbaticals in industry.

A practical orientation for students means:

- serving internships in industry as a part of their studies;
- spending a practical semester in industry;
- preparing a thesis in conjunction with industry.

Finally, a practical orientation in teaching can be achieved by:

- elucidation of theoretical subject matter by using practically oriented examples.
- inclusion of problems from industrial practice in imparting specialist subject matter.

A sufficient practical orientation is one of the central demands that industry places on an engineering education, and to achieve this most effectively, close co-operation with the universities is indispensable. An important contribution that industry can make is provision of sufficient internships for students both during vacations and also in the context of practical semesters, especially for 'Fachhochschulen' students.

German engineering education is built on this pattern, both at 'Universitäten' and 'Fachhochschulen'. The teaching of a broad foundation during the first semesters and the first part of work in the major field of study is followed, in the last semesters, by in-depth work in a freely chosen field of application. The application-oriented, technical knowledge that is imparted here provides an introduction to the questions in this field of application and advances the initial professional competency of the graduates in this area. The compulsory industrial internship during vacations or in the form of a practical semester acquaints the students with the social context and the concrete tasks of future workplaces, thus providing an indispensable contribution to the practical orientation of engineering studies. The eduational model for engineering studies described here and practised at German universities has proved successful in meeting the demands of industry.

In this connection the European dimension in engineering education must also be given increasing attention. The completion of the Single European Market and the economic integration of Europe offer companies new opportunities that they can only realize if they have personnel who are prepared for the new Europe. Personnel are needed who, in addition to excellent professional qualifications, are also familiar with other cultures. This preparation includes foreign language competency, a knowledge of the culture of other countries and a basic understanding of the political and social structures as well as the legal systems. Above all personnel must be ready to live and work in another country for a certain period of time, i.e. personal mobility. Many of these traits fall in the area of key qualifications. These demands fall into the personal area to a certain extent, and such qualifications can only be partially imparted via academic teaching. But the educational system can foster them, by making study terms or internships abroad possible for example. Here, industry would like to see more cross-border co-operation between universities and above all more mutual recognition of semesters completed abroad so that education is not prolonged by studies in other countries.

Initial training and continuing education

The knowledge acquired during an engineering course enables young graduates to assume some engineering tasks in industry immediately after graduation. They will usually be integrated into an experienced team at the beginning of their professional careers and assigned concrete tasks. Those lacking practical experience can gain it depending on the task, in a one- or two-year initial training phase, directly at the workplace. Thus, there should be a smooth transition from academic education, with its future-use component, to professional continuing education—'life-long learning'.

Companies devote particular attention to the initiation of new staff members. Careful consideration and planning is needed for the initial training of new personnel so that the inclinations and abilities, as well as the knowledge acquired during their studies, can be fully utilized. In this respect, learning on the job takes on special importance. New staff members learn via daily confrontation with problems and projects and by discussions with seniors, colleagues and customers, thus expanding their level of qualification. Individual learning through practical activity is supported and augmented in all areas by organized continuing education programmes. The emphasis of these programmes is on professional continuing education in the form of courses, lectures and colloquia.

In addition, broad scope is given to general continuing education with topics on the business enterprise, organization, working methods, etc.

But even after the initiation process is completed, an Ingenieur's need for continuing education does not subside. As a result of the progress of technology, but also due to different responsibilities, organizational changes or the firm's policy, the necessity arises for acquiring new, professionally relevant knowledge. In the present age, rapid technical change takes on a particular significance. The breathtaking developments in microelectronics and information technology and their applications in all areas of industry and in nearly all realms of life led to rapid and massive changes in knowledge and skills requirements.

Industry's present continuing education needs can be characterized as follows:

- The amount of knowledge undergoing change is nearly impossible to comprehend; the speed at which this change takes place has grown and continues to grow.
- Those affected by this change have never been so numerous;
- A rapidly growing market for continuing education has emerged.
- Continuing education has become a service that is subject to the market principle of supply and demand like any other product or service.
- There is not an unlimited amount of time available in professional life for continuing education. In light of the continuing reduction of working hours, the leeway for continuing education is becoming more and more restricted.

An example of these trends is the development of the volume of continuing education at Siemens. In 1963, the company had a continuing education program with about 200 courses for factory personnel. In 1990 there were more than 30 continuing education programs with 18,000 courses. One thousand staff members were fully employed in continuing education with more than 4000 freelance teachers.

Since substantial, new and further developments in technology are taking place not only at universities, but also at the R&D departments of industry, technical continuing education has become a domain of industry. It can be and is being conducted within the firms. For the professional continuing education of Ingenieurs in smaller companies, external institutions have been set up (e.g. technical academies), supported by course fees, with the help of industry. Continuing education activities of trade and professional associations (VDE, VDI, REFA, etc.) round out the offerings. The instructors are primarily Ingenieurs and natural scientists from industry. In so far as fundamental knowledge is imparted, university teachers are used. Universities themselves are increasingly becoming involved in continuing education. In Germany they still, however, must find their place in the overall system. In-company and external continuing education and training are thus two areas that are dependent on each other, so there must be strong linkage and feedback. The system that has arisen over the years in Germany has proved successful and ensures that, as a rule, personnel's needs for continuing education can be met efficiently and quickly.

CONCLUSIONS

Our economy's competitiveness and our standard of living depend largely on the innovative strength of qualified Ingenieurs as well as on the efficiency, productivity and quality of their work. For attaining, preserving and further developing their ability to convert technical innovations into marketable products, a well-functioning education and training system is indispensable.

Industrial firms are strongly dependent on the performance of high-quality, practically oriented engineering education at universities. The task of initial education at 'Universitäten' and 'Fachhochschulen', from an industry perspective, is the teaching of fundamental knowledge and its application in long-term use. Continuing education should be geared to daily needs and the short-term processes of change in technology and the economy. Its primary characteristics are product and problem orientation, workplace orientation and adjustment to the place of innovation.

Whereas academic engineering education must be based on a systematically designed curriculum, continuing education is an open system in which new topics with workplace relevance are constantly being incorporated. Continuing education requires a pragmatic approach. To be effective it must keep pace with technological developments, with particular importance being assigned to application areas in which technological innovations occur very rapidly.

Organized continuing education, in the form of courses, is a marketed product. From an industry perspective, the following demands are placed on 'continuing education for professionals' as a product or service:

- The course offerings must be adjusted to current educational needs and to rapid implementation at the workplace. Course content must be geared to adults and practically oriented. As a rule it is expected that continuing education provides a positive contribution for problem-solving on the job. The choice of subjects, the prerequisites for participants and the learning objectives must be in line with these expectations.
- Continuing education requires a suitable organizational framework. The employment of modern teaching methods and media makes efficient learning possible. Compact courses, evening courses and weekend seminars with concentrated instruction and teaching methods are suitable. The participants should be motivated

using teaching aids and devices that simulate those at the workplace.

- The course suppliers must engage in competition on the continuing education market. A marketing of courses that cover their costs, and an open discussion of the attainment of learning objectives and the applicability of what has been learned are the necessary feedback from course participants to improve quality

The additional and higher development of personnel is a task of the company, i.e. of the management and staff members themselves. For the senior personnel, it is a task they must perform; for other personnel a service they must demand. Both must be able to select the appropriate educational offerings from the market. Continuing educational offerings must, therefore, be sufficiently transparent and not only known to a small circle. Co-operation between suppliers and customers is desirable in order to be able to gain, wherever possible, from prior experience in analysing educational needs and in developing and marketing courses.

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